High-Performance Thermal Control Ducts

The present invention relates to high-performance thermal control ducts for heat exchanger tubes, in which one-phase liquid or gaseous substances can be thermally controlled as quickly and as uniformly as possible and with as much product care as possible and which also function for use in microstructured apparatuses as independently as possible of the respective viscosity of the substances to be thermally controlled.

Background of the invention

Product-carrying ducts, particularly in the form of pipelines, are known in the chemical industry. The thermal control capacity of these product-carrying ducts is limited, since the heat-exchanging surface is small and, depending on the flow viscosity and thermal conduction property of the respective liquid or of the respective gas, a temperature gradient occurs between the duct center and the thermally controlled duct inner surface. To intensify the thermal control processes in pipe ducts, inserts or components are known which, designated as static mixers or as turbulence elements, are used in ducts through which the product flows. When these fittings are used, the thermal control process is improved slightly. Consequently, fitted elements of this type, such as static mixers and turbulence elements, are soldered into the duct in special versions, in order to increase the heat transfer coefficient and the surface area of the thermal control surface in the product space.

It is known that microstructured apparatuses make it possible to have high heat transmission capacities. Microstructured apparatuses have parallel-arranged product-carrying ducts of square or rectangular flow cross section. This technique offers a large heat-exchanging surface in relation to the product or apparatus volume. The microstructure technique has the disadvantage of small flow cross sections, which are susceptible to clogging in the case of unfiltered substances. In production processes,

substances or products are often laden with impurities, so that the small μm-ducts (μ-range) quickly become clogged and the failure of the microstructured apparatuses occurs. For this reason, microstructured apparatuses are usually employed only in process engineering processes using high-purity starting materials. Furthermore, microstructured apparatuses are produced by means of special and cost-intensive manufacturing methods, so that material-carrying duct lengths are not available in large lengths or dimensions because such apparatuses cannot be manufactured economically.

To improve heat exchange processes, flat tubes which are produced by the flat-rolling of round tubes are known from EP-A 0 659 500. In flat tubes, the distance from the thermally controlled duct inner wall to the duct center is reduced. This version has the disadvantage of a small thermal control surface and the low stability under pressure of the flat tubes. When materials of relatively high viscosity are thermally controlled in flat ducts of this type, an uneven velocity distribution occurs, which, in turn, generates an uneven temperature distribution in the product stream. Materials of high viscosity additionally generate high differential pressures, so that, because of the low stability under pressure, these flat tubes tend to bulge and are not dimensionally stable. Moreover, high differential pressures occurring in flat tubes lead to the rectangular cross section of the flat tubes reforming and assuming a round cross section again. To increase the stability under pressure of a flat tube, the tube wall thickness may be increased, the disadvantage of this being that the thermal conduction resistance is likewise increased.

EP-A 0 302 232 discloses a flat tube for a heat exchanger, which flat tube can be produced from a bent sheet-metal strip. This flat tube may also be provided with turbulence inserts, everything being soldered together sealingly in one soldering operation. Such bent sheet-metal flat tubes can be used only for low differential pressures. As soon as the flat tube is bent up due to a high pressure, it loses the improved heat transmission properties. The stability under pressure of a flat tube described is increased by webs being worked in by folding. The webs modify the flat

tube to the effect that a multiple-duct flat duct with higher stability under pressure is obtained. The individual duct obtained in the flat tube is virtually square. However, the square flow cross section leads to only two thermal control surfaces being effective. Moreover, the distance from the duct center to the inner thermal control surface is such as to establish a temperature gradient which prevents a uniformly rapid thermal control having a degree of product care. If a material of relatively high viscosity is to be thermally controlled at a low laminar flow velocity, the temperature differences in the flow cross section are particularly pronounced.

A flat tube for heat exchangers with an elliptic cross section, turbulence elements being inserted into the said flat tube, is known from EP-A 0 624 771. The turbulence elements consist of bent wires which are subsequently pushed into the elliptic tube and, by virtue of the bend contour, are jammed in the elliptic flat tube. Turbulence inserts can be used for the thermal control of aqueous materials at high flow velocities. The thermal control process for liquids of high viscosity with low flow velocities is not decisively improved by means of these turbulence elements bent from wire.

EP-A 1 213 556 describes flat tubes with a plurality of flow regions which are arranged next to one another and which issue in a collecting tube. The flat tubes consist of a plurality of parallel flow ducts, so that the walls of the individual chambers have a pressure-stabilizing action on the shape of the flat tube. A plurality of parallel-arranged flat tubes which all issue into a collecting tube form a heat exchanger. The shape of the flat tube described is produced by the extrusion method, for example with aluminum. The production of these flat tubes is complicated and special tools are required. Consequently, flat tubes of this type cannot be produced in highly corrosion-resistant materials.

US-A 5,050,671 discloses a panel heat exchanger formed from two sheets of thermoplastic polymer.

Finally, US-A 5,826,646 describes a flat-tubed heat exchanger consisting of two plates to be used in a two-phase system wherein the heat transfer fluid flowing in the heat exchanger tubes includes both liquid and vapor. This heat exchanger is not that efficient whenever only a one-phase system has to be thermally controlled.

The object, therefore, was to considerably improve the known disadvantages of the plate heat exchanger technology and the tubular heat exchanger technology and to provide high-performance thermal control ducts for use in heat exchangers for the thermal control of one-phase liquid and gaseous substances in production engineering (on a cm-scale), on the laboratory and industrial scale (on a mm-scale) and in microstructure technology (on a μm-scale), which have rapid and uniform thermal control having a high degree of product care over a relatively large viscosity range (up to 100,000 mPas) with a simultaneously low hold-up and a large heat-transfer surface on the product side. The high-performance thermal control duct should be particularly robust and compact, so that high pressure stability (up to 500 bars) is obtained without the high-performance thermal control duct requiring any additional supporting components. The requirements for compact design, low hold-up and effective product mixing in the duct broaden the problem to be solved. In addition, the aim was to considerably reduce known operational problems such as fouling and the risk of blockages associated therewith.

Summary of the invention

The solution to the problem and therefore the subject matter of the invention are high-performance thermal control ducts for high differential pressures and large thermal control ranges, comprised of two sheets or layers which are laid, or sandwiched together opposite, one on top of the other and which have one-sided depressions introduced in their parting or contact plane, wherein the height of the individual high-performance thermal control duct is no greater than the thickness of the sheets used and the individual depressions are worked into the sheet in a material-removing and/or material-displacing manner and form sharp edges towards the sheet-

parting plane, and the sheet thickness in the region of the depressions is reduced locally by up to 90%, and depressions having an identical depression area and an identical depression volume lie next to one another in the sheet-parting plane and have no connection to one another, and a plurality of depressions lying next to one another form a depression row or depression chain,

the geometric area of each depression has a greater extent in relation to the sheet width than in relation to the sheet length,

the larger longitudinal axis of each depression is at an angle α of 5 - 85 degrees to the mid-axis of the depression row or depression chain, one sheet being rotated by 180° with respect to the other sheet, with the result that at least three depressions which are at an identical angle partially overlap and/or intersect one another and form a throughflow duct, the flow cross section of which is in the region where the two sheets face each other,

and

at least one holed sheet as a turbulence exciter is inserted between said two sheets and the throughflow duct is stable under pressure.

The high-performance thermal control ducts according to the invention, which in the simplest instance constitute an individual flow duct with a unitary flow cross section, are eminently suitable for thermally controlling both monophase liquid and gaseous substances to the desired temperature quickly, uniformly and with a high degree of product care. They are particularly suitable in the embodiment of flat ducts and are therefore the most suitable for use in heat exchangers where liquids (or gases) have to be cooled down or heated up within a very short time.

Detailed Description

The high-performance thermal control ducts according to the invention, formed from a multiplicity of identical depressions which have sharp edges towards the plane parting the sheets and are positioned one behind the other, form, in the region where the two sheets face each other, a flow cross section which is constant over the entire sheet length or duct length, so that, at the same time with a complete inflow into the flow cross section and a complete outflow from the high-performance thermal control duct, a uniform flow viscosity profile which is akin to a plug flow is maintained, so that even under laminar to turbulent flow conditions, a narrow dwell-time spectrum allows the thermal control of temperature-sensitive substances in an extremely short time (within the millisecond range). In addition, the high-performance thermal control duct is insensitive towards pressure variations in the throughflow, so that an identical flow velocity profile always prevails.

It is therefore also an object of the present invention that the supplying and discharging cross sections for the fluid are equal to or greater than the flow cross section of the high-performance thermal control duct, the said flow cross section being constant over the entire length.

When a flow passes through the high-performance thermal control duct, a narrow or small dwell-time spectrum is formed, and the flow of the product to be thermally controlled is constantly redirected and mixed completely, vertically and horizontally, over the entire flow cross section, so that temperature differences occurring between the thermally controlled wall and the middle flow region when the fluid flows through in the high-performance thermal control duct are quickly compensated, and there is no temperature-induced product damage. In addition, because of the uniform temperature spectrum in the product-side flow cross section, thermal control always takes place with a maximum possible temperature difference.

Adjacent depressions forming a row of depressions in a high-performance thermal control duct have depression areas which are identical in the sheet plane, although the depression volume of adjacent depressions can vary in size, so that locally higher flow speeds and lower hold-ups are produced, while the heat-exchange surface area is reduced. Surprisingly it was found that, despite a smaller heat-exchange surface area, the thermal control capacity is not proportionately reduced.

Another preferred object of the present invention is the fact that adjacent depressions having an identical depression area in the sheet-parting plane have different depression volumes and form a high-performance thermal control duct which thus has sections having different hold-ups and different flow speeds.

A high performance thermal control duct formed from different, alternating depression volumes, as a result of which adjacent depressions having different depression heights are incorporated in individual sheets of the same thickness, can also be obtained by using two sheets of varying thicknesses to form a duct, in which the depressions locally produce an identical reduction in sheet thickness, as a result of which different flow speeds are produced in each sheet.

Another preferred object of the present invention is the fact that a high-performance thermal control duct consists of two sheets of different thicknesses, in which depressions having identical depression areas in the sheet-parting plane but identical or different depression volumes are incorporated and depressions having different volumes are positioned alternately in the direction of flow in one sheet or alternately in both sheets.

Alternately varying depression volumes in the sheets produce a pulsating flow speed in the direction of flow, while acting against fouling.

The high-performance thermal control ducts according to the invention are particularly suitable for the thermal control of batch materials of the most diverse viscosi-

ties, preferably in a viscosity range of between 0.1 mPa·s to 100 000 mPa·s, particularly preferably of 0.1 mPa·s to 10 000 mPa·s.

With the respective viscosity of the batch material, the flow processes in the high-performance thermal control ducts according to the invention lie in the laminar to turbulent range, and, depending on viscosity, differential pressures of 0.1 bar to 500 bar, preferably of 0.1 bar to 100 bar, and particularly preferably of 0.1 to 50 bar, prevail.

The high-performance thermal control ducts according to the invention are particularly suitable for thermal control in a wide temperature range of -80°C to 500C, particularly for a temperature range of -20°C to 325°C and, particularly preferably, for the range of 20°C to 200°C.

The large temperature range, particularly in combination with the various materials employed, allows use for almost all set objects.

In the high-performance thermal control ducts according to the invention, however, two or more substances may also be thermally controlled simultaneously. In this case, it may happen that these react with one another and release reaction heat which has to be discharged directly. It was shown that, owing to the geometry of the depressions, the high-performance thermal control ducts according to the invention have a large heat-transfer surface on the product side and a lower hold-up than comparable thermal control ducts known from the prior art. At the same time, because of their internal geometry, the high-performance thermal control ducts according to the invention exert a high mixing action over the entire flow cross section on the substances flowing through and thus avoid temperature gradients in the liquid or gaseous medium/mixture flowing through.

The subject of the present invention is therefore also that the high-performance thermal control duct is employed as a flow reactor when two different substances, which together generate a new substance, are supplied.

It has been found that the low product-side volume due to the volumetric geometry of the depressions and the good intermixing by means of the sharp-edged depressions have a positive effect on the dwell-time spectrum. Particularly where substances of higher viscosity are concerned, the dwell-time spectrum is markedly reduced, as compared with the thermal control ducts from the prior art.

The sharp-edged transitions to the depressions prevent wedge-shaped gaps in the region of the sheet-parting plane, so that no product deposits occur in these regions and fouling is avoided.

The large number of depressions in the sheets or in the sheet layers which lie next to one another and have a large extent in relation to the sheet width and which form a depression row or depression chain have no connections to one another in the respective sheet plane (Fig. 1). As soon as two sheets are laid together and identical or similar depression rows lie with their depression areas and depression volumes directly opposite one another, partially overlapping and intersecting cavities located opposite one another are formed (Fig. 2). A liquid or gaseous material flowing through flows back and forth between the depressions of the two sheets and the fluid is constantly intermixed. Consequently, no pronounced temperature gradients arise, and a rapid and uniform thermal control of the material flowing through takes place. The longitudinal axis of the depression, the said longitudinal axis being at the angle α, and consequently also the delimiting walls of the depressions act as guide surfaces or deflecting contours (Fig. 2). Moreover, they assist a transverse flow in relation to the longitudinal axis of the depression. Temperature-sensitive substances can be protected, by virtue of the mixing action, against thermal damage.

The introduced depressions have their largest area at the surfaces of the sheets or layers upon which they are formed, i.e., in the "parting" or "contact plane" of the layers. With increasing parallel distance from the parting or contact plane (i.e., from the surface into the interior of the sheet or layer), the geometric area of the depression decreases. Inclined surfaces at an angle to the overall flow direction through the thermal control duct are thus formed in the layers from the contact plane up to the maximum depression height. These surfaces or guide surfaces may be straight or curved, so that they steer the material flowing through into the depressions located opposite one another and assist a positively guided flow.

The large number of depressions in the sheets or in the sheet layers which lie next to one another and have a large extent in relation to the sheet width and which show a depression row or depression chain have the same depression area but the depression volume might differ in a depression row. Surprisingly, higher local flow velocities and a smaller hold-up and a different pressure loss are formed at the same time. It is therefore an object of the present invention that depression rows with the same depression area in the same sheet layer are formed but with a different depression volume.

The lateral surfaces, inclined or curved in the flow direction, of the depressions are at an angle β from the contact plane to the highest level of the depression. In other words, if an imaginary line is drawn from the highest point of the rib formed by two depressions lying next to one another and located at the level of the contact plane to the lowest point of the depression, this imaginary line forms an angle β to the contact plane or to the overall flow direction.

These curved or inclined surfaces assist the “vertical mixing effect” and steer the material flowing through into the opposite depression row. The curved or obliquely set surfaces counteract possible material deposits, particularly at prevailing laminar flow velocities so that the flow passes through all the regions of the high-

performance thermal control duct efficiently and uniformly. If the lateral surfaces are straight, they are at a preferred angle β of 60 degrees.

In all preferred versions, the lateral surfaces of the depressions in the layer are at an angle β of 20 to 80 degrees, preferably at an angle of 40 to 60 degrees.

The opposite lateral surfaces of a depression 2 in Fig. 1a in a layer may differ from one another, so that the surface 3 on the inflowing side of the depression has an angle of β' and the surface 3' on the outflowing side is at an angle β. The two angles β and β' have an angle of 20 to 80 degrees.

The high-performance thermal control ducts may advantageously be produced, for example, from sheets having thicknesses of 0.5 mm to 50 mm.

Since the longitudinally extended depressions are transverse or at an angle to the overall flow direction, the medium flowing through in the high-performance thermal control duct is divided once or more than once and is subsequently combined again and thereby constantly intermixed, so that there are no temperature peaks and rapid temperature equalization and therefore thermal control having a high degree of product care take place.

The longitudinally extended depressions preferably assist the "horizontal mixing effect" on the material flowing through.

The length of the depression, the said length being determined at right angles to the main flow direction, is identical to the inner width of the flat duct and is smaller than the layer or sheet width. The doubled depth of the depression in the individual sheet is identical to the internal height of the flat duct and is always smaller than twice the sheet thickness. This results in the gross flow cross section of the flat duct. The depression row is always equivalent to the individual high-performance thermal control duct.

The center-to-center distance between two depressions of a depression row is at least as great as the width of the depression, in order to design a low-gap thermal control duct. A preferred ratio may be formed in which the depression width to the center-to-center distance of the depressions is greater than 1. In this case, the edges of the depressions on the respective layer surface are in contact with one another only in a punctiform manner in the parting plane. There are no gaps which promote product deposits and are possibly conducive to a blockage of the thermal control duct.

In particular versions of the high-performance thermal control ducts according to the invention, the ratio of depression width to center distance is greater than 0.7 to lower than 2, preferably greater than 0.8 to lower than 1.5, and particularly preferably the ratio is greater than 1 to lower than 1.1.

The sheet strips or layers provided with depressions in the high-performance thermal control ducts according to the invention have a non-structured edge region which is closed sealingly during a welding or soldering operation. The welding of the two sheets or layers together to form a high-performance thermal control duct leads to pressure-tight and highly stable flow ducts.

The non-structured edge regions may likewise be provided, parallel to the depression row, with small depressions in the form of grooves, so that these depression grooves in the edge region function as a soldering-medium repository. For example, pasty solder introduced there can connect the layers to one another in a soldering furnace.

The depression or the depression rows for forming a high-performance thermal control duct can be introduced into the sheet or into the layer efficiently by means of various manufacturing methods. Chip-removing or material-stripping manufacturing methods and also material-displacing methods may be employed. A further manufacturing alternative is casting technology.

By material-removing or material-displacing manufacturing methods are meant, for example, drilling, milling, planing and lathe-turning. Those material-stripping methods also include, for example, etching and erosion. Depending on the depression size and depression shape, a material-displacing forging or stamping technique could also be an economical manufacturing alternative. If particularly large quantities of identically designed layers are required, casting methods may also be employed. The cast layers need only be welded or soldered together to form a duct.

In the high-performance thermal control duct according to the present invention the heat exchange surface is increased by more than 10% in relation to the determined sheet surface or layer surface of the flow region of the individual layer and in comparison to a heat exchanger according to the prior art. In a preferred embodiment, the increase in the heat exchange surface is in the range of 10 to 70%, particularly preferably 10 to 50% in comparison to the prior art.

Casting technology also affords the possibility that a high-performance thermal control duct can be produced in one piece by the use of mould cores, so that a longitudinal welding of the layers with depressions is dispensed with. Producing a high-performance thermal control duct by casting technology is economical particularly when materials with high heat transfer coefficients, such as, for example, aluminum, chromium, nickel and copper and their alloys, can be used from the point of view of the relevant application.

It is therefore also inventive that a high-performance thermal control duct can be produced in one piece by the casting method.

In a sheet-metal plate, for example, a plurality of depression rows arranged next to one another in parallel can be worked in, so that, on the same principle of two sheet-metal plates laid one onto the other, even greater product streams can be thermally controlled quickly and with great care in a short time. Depression rows arranged next to one another in parallel in sheet-metal plates can be introduced simultaneously in

one operation, so that the manufacturing costs can once again be reduced considerably.

Sheet-metal plates with a plurality of depression rows form the industrial basis for the construction of cost-effective duct heat exchangers or plate heat exchangers.

In a preferred embodiment, the components of a high-performance thermal control duct which are designated as sheets are made of corrosion-resistant materials. Mention may be made here, by way of example, of glass, ceramic, graphite, conductive plastics, in particular UV-permeable and resistant plastics, chrome-nickel steel, nickel alloys and non-ferrous materials, such as, for example, aluminum.

In a further preferred embodiment, the depressions in the sheets which are components of a high-performance thermal control duct or flow duct are coated with a catalyst, in order to accelerate or promote a reaction taking place in the flow duct.

Within the scope of the work relating to the present invention, it was found that, the greater the longitudinal extent of a depression is in the main flow direction, along with a correspondingly small depression width, a depression overlaps and intersects with a plurality of depressions of the opposite sheet. This promotes a reinforced horizontal mixing action and improves the thermal control process. Consequently, no temperature gradients occur in the material stream to be thermally controlled.

To achieve this effect, a height/width ratio of the depression in the sheets of greater than 1, preferably greater than 5 and particularly preferably greater than 10 is selected.

The height taken into account in the formation of the height/width ratio corresponds to the inner width of the flat duct. The width of the depression corresponds to the depression extent in the main flow direction or duct length.

The present invention therefore relates to high-performance thermal control ducts, in which each depression of an individual layer intersects or overlaps with at least 3 depressions of the opposite layer or holes of the holed sheet, preferably intersects or overlaps with more than five depressions or holes and particularly preferably with more than ten depressions or holes of the opposite depression row of the second layer or holed sheet.

Within the scope of the present invention, it was found, surprisingly, that the formation of a large height of a depression scarcely weakens the carrier sheet in terms of the compressive load which occurs. The inner product-side ribs between the depressions stabilize the carrier sheet with regard to high differential pressures and serve as reinforcing ribs, so that there is a stiffening which withstands a high compressive load and no other supports are necessary for the high-performance thermal control duct.

By virtue of different wall thicknesses towards the heating or cooling side, the heat transfer capacity rises, since a locally smaller wall thickness has a lower heat transfer resistance. The edge regions between the depressions lie next to one another, also designated as reinforcing ribs, have a higher heat transfer resistance by virtue of the material thickness towards the thermal control space, so that a medium heat transfer resistance must be expected between the full carrier-sheet thickness and the smallest sheet thickness.

The edge regions of the depressions additionally form a heating-surface enlargement, so that the efficiency of the high-performance thermal control duct is increased.

In fluidic terms, the medium to be thermally controlled is swirled upon inflow into the flow cross-section of the duct having depressions and the heat transfer capacity is increased. In particular, the sharp-edged transitions on the edges of the depressions provide additional accelerator stall accompanied by turbulence.

The invention therefore relates preferably to high-performance thermal control ducts, in which the depressions in the sheets have a height of up to 90%, preferably of greater than 10% to lower than 70%, and particularly preferably of greater than 10% to lower than 60% of the sheet thickness.

Within the scope of the present invention, it was found that the angle α (Fig. 1), in conjunction with the height/width ratio, determines the overlap and intersect frequency of the depressions located opposite one another and influences the differential pressure of the flow duct which occurs at a constant fluid velocity. The smaller than angle α is in the case of a constant height/width ratio, the lower is the pressure loss.

The present invention therefore relates preferably to high-performance thermal control ducts, in which the geometric longitudinal axis of the depressions in the sheets is at a preferred angle α of 20 to 70 degrees and particularly preferably at an angle of 40 to 50 degrees to the depression row or to the overall flow direction.

Within the scope of the present invention, it was found that, by virtue of the large heat-transfer surface, in combination with a low hold-up, only a small length of the high-performance thermal control duct is required in order to achieve virtually complete temperature equalization between the heat transfer medium and the product stream. It is particularly advantageous to use the high-performance thermal control ducts according to the invention when there are only small temperature differences between the heat transfer medium and the product being heated or cooled.

The invention therefore relates preferably to high-performance thermal control ducts, in which the depression row of a sheet or of a layer has fewer than 1,000 depressions, preferably fewer than 500 depressions and particularly preferably fewer than 250 depressions.

Within the scope of the present invention, it was found that flow ducts with a substantially lower pressure loss are obtained when these consist of three sheets with at least one or optionally further intermediate sheets with holes.

In this case, there are inserted between two sheets with depressions introduced on one side, which are also referred to as outer sheets, one or more additional sheets with one or more rows of holes, with a geometry identical to or, if appropriate, different from the depressions of the lateral sheets, but without exceeding the width range of the depression rows.

The invention relates to flow ducts consisting of two sheets with depression rows introduced on one side and of at least one sheet inserted between these two sheets and having one or more rows of holes which do not exceed the width range of the depression rows, so that a flow duct consisting of at least three sheets/layers is obtained, which has a substantially reduced pressure loss.

The holed sheet inserted serves as an additional turbulence generator, reduces the pressure loss for a constant volume flow and does not generate any additional gaps in the soldered state.

The holed sheets employed are usually welded or soldered to the adjacent outer sheets with depressions. Holed sheets can also be employed as detachable turbulence-producing means in high-performance thermal control ducts.

The holed sheets can have different orifices (cf. Figs. 9 to 9d), so that in the sheet-parting planes the areas of the orifices and depressions can have identical and/or different geometries. The choice of the geometry to be used for a high-performance thermal control duct depends on the thermal control problem concerned.

The orifices in these holed sheets are obtained by means of punching methods, etching methods or drop-erosion methods.

According to the invention, depressions can be pressed into the sheet by means of an embossing or drop-forging method, with the layer thickness being maintained. These are methods of forming technology. The depressions are preferably in the form of grooves with a semicircular cross section (Fig. 4, Fig. 4a, Fig. 4b).

The surface of the depressions in the sheets may be of different geometry and can be adapted or optimized to the substances to be thermally controlled (Fig. 3, Fig. 3a, Fig. 3b, Fig. 3c). The examples shown are merely illustrative, but not limiting.

The workpieces, designated as sheets, are welded to one another, for example parallel to the depression rows, along the longitudinal edges. Preferred welding methods are TIG (Inert-Gas Welding), laser, EB (Electron-Beam Welding) or rolled-seam welding.

In a preferred embodiment of the high-performance thermal control ducts, depressions for receiving a solder are provided in the edge regions of the carrier sheets, the depressions performing the function of a solder repository. The depressions receiving the solder are connected to one another by means of ducts or grooves, so that homogeneous soldering can take place. The solder repositories are smaller than the product-touched depressions (Fig. 5).

The ducts or grooves for receiving the solder may be positioned in such a way that a gap-free high-performance thermal control duct is obtained after soldering. The gap-free version is particularly advantageous for applications in the food, pharmaceutical and bio-engineering industry.

According to the invention, two sheets lying against one another, with introduced depressions, and a holed sheet in between form a closed product-carrying flow duct with a high heat transmission capacity, the high-performance thermal control duct according to the invention. It may happen, in this regard, that the outer thermal

control surface of the three-layer system is too small, so that the outer sides facing away from the product may likewise be provided with depressions for the formation of thermal control ribs. This appreciably enlarges the outer heat transfer surface.

When the high-performance thermal control ducts according to the invention are used as coolers and the cooling medium is, for example, air, the outer cooling surface of the high-performance thermal control duct may then be provided with cooling ribs which, if appropriate, are also soldered to the duct.

The high-performance thermal control ducts according to the invention, formed from at least two sheets with depression rows located on one side of each and a holed sheet, may be combined with known flow ducts, such as, for example, simple tubes equipped with known static mixers, or, for example, with what are known as profile tubes having turbulence inserts or flat ducts.

These are eminently suitable as flow reactors for carrying out chemical reactions.

A plurality of parallel-arranged high-performance thermal control ducts according to the invention, comprising in each case three sealingly welded or soldered sheets/-layers with inner structures and holes, the structures being depressions or forming depression rows, may simultaneously receive an inflow and form a duct-bundle heat exchanger or a plate-duct heat exchanger (Fig. 7).

High-performance thermal control ducts layered one above another and in each case arranged so as to be offset at 90° to one another may form a cross-current heat exchanger. In the cross-current heat exchanger, high-performance thermal control ducts with a low hold-up and a small dwell-time spectrum are used in each case on the product side and on the thermal control side, so that intensive temperature equalization takes place, along with a small product volume and thermal control medium volume (Fig. 8).

It is advantageous, in this case, to use layers with depressions introduced on both sides of the outer sheets, in order to minimize the number of layers and to promote a compact form of construction. A reduction in pressure loss is achieved in the case of the cross-current heat exchanger, when high-performance thermal control ducts with an inserted holed sheet are used on the pressure-critical side of the heat exchanger.

The high-performance thermal control ducts with at least one holed sheet according to the invention but even thermal control ducts with no holed sheet may also be used in a cross-current heat exchanger and, moreover, are suitable as flow ducts

- in a sterilizer for the sterilization of water or of pharmaceutical or biological substances,

- for use in photo-bioreactors for the breeding of microorganisms.

The high-performance thermal control ducts with at least one holed sheet according to the invention but even thermal control ducts without holed sheet are suitable, furthermore, as miniaturized flow ducts on chips for diagnostic purposes.

Brief description of the drawings:

Fig. 1: shows a sheet-metal strip with eroded depressions which are positioned next to one another and are at the angle α to the overall flow direction (9) through the thermal control duct to be formed with the strip.

Fig. 1a: is an illustration of section of Fig. 1, from which it can be seen that the lateral surfaces of the depressions, which depressions are themselves at the angle α, and having an angle β (inflowing side) or β' (outflowing side) to the overall flow direction.

Fig. 2: shows two sheet-metal strips according to Fig. 1 which are laid one on the other and form a flat duct for a heat exchanger, the upper sheet (1') being partially open, so that the outlines of the depressions lying one above the other can be seen.

Fig. 2a: shows section of the flat duct from Fig. 2 with the overall flow direction (9), with the inner depression rows located opposite one another.

Fig. 3-3c: show alternative contours of the depressions.

Fig. 4-4b: show cross sections of the depressions.

Fig. 5: shows a sheet-metal strip (i.e., a sheet) which has grooves serving as soldering repositories in the edge regions.

Fig. 6: shows depression rows with a depression according to Fig. 3 in a flow duct.

Fig. 7: illustrates a parallel arrangement of high-performance thermal control ducts with depression rows, which are inserted in a thermally controlled housing and welded together and which form a duct heat exchanger.

Fig. 8: shows a sheet-metal strip having grooves on both sides.

Fig. 8a: shows the front of the sheet-metal strip having grooves on both sides.

Figs. 9-9d: show different types of orifices and orifice arrangements for holed sheets.

Examples

Fig. 1 illustrates a carrier sheet 1 with depressions 2. The depressions have a trapezoidal cross-sectional surface and are worked into the sheet or into the layer at a distance from and adjacent to one another and thereby form a depression row 2', 2''. The geometric axis 4 of extent of the depressions is at an angle α transversely to the center axis 5 of the depression row and to the overall flow direction 9. The depressions of the depression row are formed only partially at the sheet ends 6, 6', so that inflow orifices 7 and outflow orifices 8 are formed at the ends of the sheet. The depression row 2, 2', 2'' at the same time defines the main flow direction 9 of the thermal control duct to be formed. Above and below the depression row as illustrated are located narrow edge regions 10 which may be welded or soldered to corresponding edge regions of a second carrier sheet, in order to produce a pressure-tight flow duct with a high thermal control capacity.

In Fig. 1a, a sectional view of carrier sheet 1 is illustrated. The carrier-sheet thickness 11 and the depressions 2, the height of which is less than the carrier-sheet thickness, can be seen. In this version, the depth of depression is 50% of the sheet thickness. In the sectional illustration, it can be seen that the lateral surface 3 on the inflowing side of the depression has an angle β' and the surface 3' of the outflowing side has an angle β in the overall flow direction, so that the flow passes optimally through the depression, a vertical mixing action in relation to the opposite depression row is assisted and, as a result, product deposits are prevented.

In Fig. 2, two layers or sheets 1, 1' are laid one on the other, the second sheet 1' having been rotated through 180 degrees with respect to the first and lying on the lower sheet 1, and the upper sheet 1' being opened partially to reveal the depressions. What can be seen are the overlapping and intersecting depressions and the inner webs which are formed between the depressions and which generate a horizontal mixing action, parallel to the longitudinal extent of the depressions, by the deflection and division of the main stream. When flow ducts are under a pressure load, the inner

webs act at the same time as reinforcing ribs and thereby increase stability under pressure.

Fig. 2a illustrates a section of the two-layer duct illustrated in Fig. 2, but with a reduced length. It can be seen clearly that the lateral surfaces 3 of the depressions 2, the said lateral surfaces being at the angle β in the flow direction, assist a vertical mixing action and form virtually no regions where the throughflow is insufficient. It can be seen, furthermore, that the rib intersection points of the depressions lie one on the other only in a punctiform manner and there is no great gap formation in the region where throughflow takes place. In this presented version, the ratio of depression width to center distance = 1.

Fig. 3 to 3c show various forms of depression surfaces. Fig. 3 shows an elongate depression with obliquely set lateral surfaces. Fig. 3a illustrates a form which can be produced typically by the drop-erosion method, so that the lateral surfaces of the depression which are located in the flow direction are at an angle and the upper and lower edge surface of the depression run perpendicularly into the sheet. Fig. 3b shows a longitudinally extended depression which may be formed by means of a plurality of countersinking operations. Fig. 3c shows typically a depression which has been generated in a chip-removing manner by means of a radius or spherical milling cutter. It is advantageous, in this form, that the flow passes efficiently through all the regions and the dwell-time spectrum is small.

Fig. 4 to 4b show various preferred cross-sectional forms of depressions, for example a trapezoidal version (Fig. 4), an acute-angled version in the form of a triangle (Fig. 4a) and a circle segment (Fig. 4b) or semicircle. The cross-sectional form of Fig. 4b corresponds to the depression surface form from Fig. 3c. It can be seen from fig. 3 to 3c and 4 to 4b that depressions form surfaces always conducive to better flow routing.

Fig. 5 shows a portion of a sheet 1 with, for example, longitudinally extended depressions 2 having the cross-sectional form according to Fig. 4 and with a depression surface corresponding to Fig. 3, a radius being arranged at the upper and lower end of the depressions. Above and below the depression row illustrated, a groove 12 running parallel to the center axis 5 of the depression row is provided for receiving a solder. The groove for receiving the solder may also be adapted to the outer contour of the depression row, so that soldering closes all the gaps of the two sheets lying one on the other and having depression rows and prevents a product deposit. Even in the case of an interposed holed sheet for reducing the flow loss, all the gaps in the edge region of the depression row are closed.

Fig. 6 illustrates a flow duct which is formed from two sheets 1, 1' laid one on the other and having depressions, in a similar way to what is shown in Fig. 5. It can be seen clearly that a fluid is divided in the inflow region along the throughflow direction 9 of the duct by virtue of overlapping and intersecting depressions and is subsequently combined again. These flow processes produced parallel to the sheet width generate a horizontal mixing effect, whilst the lateral surfaces 3, 3' of the depressions, the said lateral surfaces being at an angle β, ensure the vertical mixing effect.

Fig. 7 illustrates by way of an example a parallel arrangement of high-performance thermal control ducts 70, through which the flow passes in parallel. The high-performance thermal control ducts are inserted in an onflow and outflow plate 72, 72' and are welded to this. The onflow plate 72 on the inlet side and the outflow plate 72' on the outlet side of the product are, in turn, inserted into a housing 71 and welded. The housing 71, which at the same time forms the thermal control space, has a thermal control medium supply connection piece 73 and a thermal control medium discharge connection piece 74. A cold transfer medium or a heat transfer medium can be fed into the housing 71, in order thermally to control uniformly, quickly and with great care the high-performance thermal control ducts and the product 75 flowing through these. For the better mounting of the heat exchanger in existing plants,

connection possibilities, not illustrated here in the diagram, such as, for example, flanges or product-side connection pieces, are provided.

Fig. 8 illustrates by way of an example a metal-sheet strip 80 for a thermal control duct with grooves 83, 84 on both sides. What can be seen are the inner webs 81 of the grooves being at the angle β in the flow direction. The grooves of the other side of the metal-sheet strip are shown by intermittent lines.

Fig. 8a illustrates the front or the inflow or outflow side of a metal-sheet strip 80. Fig. 8a clearly shows that because of the grooves 83 and 84 on both sides of the metal-sheet strip the sheet itself can become very thin in the area of the depressions.

Figs. 9 to 9d show different hole patterns and hole arrangements for a turbulence-generating holed sheet for the high-performance thermal control duct. The rows of holes can be arranged in a single row or in several rows and the orifices can be arranged in parallel or in a staggered fashion, depending on the problem to be solved. Care must however be taken not to position in the sheet-parting plane geometries which, in relation to the adjacent sheet with depressions, have equally sized areas or are of the same type or point in the same direction.